

ATP

The main source of immediate energy in all organisms is ATP, or adenosine triphosphate. ATP and closely related compounds furnish the energy for cell growth and cell reproduction, muscle contraction, and other chemical processes. ATP may even be converted into light energy in organisms like the firefly. The ATP molecule comprises a nitrogen compound, adenine, linked to a molecule of sugar, ribose, to form adenosine. On the adenosine molecule is a chain of three phosphate groups that can be removed one by one to produce ADP (adenosine diphosphate, having two phosphate groups), and AMP (adenosine monophosphate, having only one phosphate). As each phosphate group is removed, the bond that connects it to the rest of the molecule breaks, releasing energy for the cells to use in their various activities. The most important reactions involving ATP are those in which the ATP donates one of its phosphates to another type of molecule to activate it. For example, glucose (a sugar), a major energy source, does not react at body temperature unless it receives a phosphate. In vertebrate muscle and brain cells, excess ATP molecules are joined to the chemical compound creatine (phosphocreatine, or creatine phosphate), which then serves as a reserve form of energy. In the invertebrates, phosphoarginine serves the same function. In 1992, ATP was found to be an important neurotransmitter.

Reviewed by Louis Levine

blackbody radiation

A blackbody is an object that absorbs all the energy that falls upon it. Because it reflects no light, it would appear black to an observer. (No perfect blackbody exists in nature, but surfaces coated with carbon black or soot absorb 97 percent of incident energy.) A blackbody is also a perfect emitter. At any specified temperature, a blackbody emits, in each part of the electromagnetic spectrum, the maximum energy obtainable from any radiator because of its temperature alone. Such emitted energy has characteristic energy distribution properties and is called blackbody radiation. Comparison of radiation emitted by real objects with that of a theoretically ideal blackbody can give information about the thermodynamic properties of materials. Also, the ability to accurately explain blackbody radiation enables scientists to test the validity of physical laws.

Toward the end of the 19th century, intensive studies were made to correlate the energy and spectral distribution of blackbody radiation. In 1879, Josef Stefan discovered through experimentation that the radiant energy is proportional to the fourth power of absolute temperature. The same conclusion was reached in 1884 by Ludwig Boltzmann from theoretical considerations and is known as the Stefan-Boltzmann law. This law shows that if the temperature T is doubled—for example 273K to 546K (32 deg F to 524 deg F)—then the radiated energy increases 16-fold. Large amounts of energy must be supplied to achieve high temperatures because of the high loss by radiation.

The unsatisfactory attempts to calculate the energy radiated from a blackbody at a specified wavelength (represented by the lower-case Greek letter λ) by classical methods (MAXWELL'S EQUATIONS for electromagnetic waves and the laws of motion of particles) resulted in the development of quantum theory. In 1896, Wilhelm Wien derived expression for spectral radiant emittance. Wien's radiation law matches experimental observations closely except for large values of λ . Lord Rayleigh and James Jeans applied classical statistical mechanics to the radiation to derive a formula, the Rayleigh-Jeans law, which is accurate for large wavelengths but fails for short wavelengths (predicts, in fact, that as λ approaches zero the energy becomes infinite—the "ultraviolet catastrophe").

In 1900, Max PLANCK proposed an expression that is accurate for all wavelengths. He developed this law strictly from experimental results, but shortly thereafter he derived it from theoretical considerations. The remarkable feature of his work is that it required the assumption that energy is not continuous but exists in discrete bundles, later called quanta (see QUANTUM MECHANICS). The size of a quantum was determined by a constant, h , called PLANCK'S CONSTANT. Although Planck still tried to justify his blackbody radiation law on classical grounds, the appearance of h in Einstein's photoelectric theory (1905) established the quantum hypothesis and began a new era for physics.

Bibliography: Cardena, M., and Ley, L., Photoemission in Solid I: General Principles (1978); Condon, E. W., and Odishaw, Hugh, eds., Handbook of Physics, 2d ed. (1967); Donski, A. V., et al., Physics and Technology of Low-Temperature Plasmas, ed. by S. V. Dresvin and H. V. Eckert (1977); Ingram, D. J., Radiation and Quantum Physics (1974); Mitchell, A. C., and Zemansky, M. W., Radiation and Excited Atoms (1971); Reimann, Arnold L., Physics: Mechanics and Heat (1971).

See also: PHOTOELECTRIC EFFECT; THERMODYNAMICS.

Carnot cycle

{kahr-noh'}

The Carnot cycle is the ideal reversible operating cycle of a thermodynamic HEAT ENGINE. It was proposed in 1824 by the French engineer Sadi Carnot. Real heat engines do not operate on the Carnot cycle, for practical reasons. Nonetheless, Carnot's ideal cycle is important in that it sets a standard for the maximum useful work a heat engine can perform.

The first law of THERMODYNAMICS, which is the law of conservation of energy, states that nature does not allow any device to discharge continuously more energy than it accepts. This law does not deny the possibility of a heat engine that operates at 100% efficiency (that is, a PERPETUAL MOTION MACHINE). Designers of heat engines, however, must also contend with the second law of thermodynamics, which limits the efficiency to values below 100% because of an unavoidable degradation in the quality of energy. Carnot sought to devise the most efficient cycle possible under these natural constraints. His result is a combination of two isothermal (constant temperature) and two adiabatic (no heat transfer) processes. These processes take place under reversible conditions; that is, they occur as a succession of equilibrium states.

The Carnot cycle is most easily understood by considering a volume of an ideal gas trapped in a closed, perfectly insulated container. One wall of the container is formed by a movable piston, while another wall may be either insulated or exposed to one of two infinite heat reservoirs at temperatures a and b . The cycle begins with the isothermal expansion of the gas upon accepting heat energy at temperature a from the hotter of the two reservoirs. The container is then insulated from the surroundings, allowing the gas to further expand adiabatically by drawing upon its own internal energy. Both expansion phases of the cycle cause an outward motion of the piston, which may be harnessed to do useful work. The third phase of the cycle involves the isothermal compression of the gas and the rejection of heat energy to the colder reservoir at temperature b . Finally, the container is once again insulated and the gas is compressed adiabatically, returning the piston to its original position and completing the cycle. Thus, the Carnot cycle accepts heat energy from its surroundings and converts a portion of that energy to useful work.

The efficiency, e , of the Carnot cycle is given by the formula $e = 100\% \times (1 - a/b)$. This formula shows that the cycle can never reach 100% efficiency unless the temperature b is absolute zero, which is a practical impossibility. Real heat engine cycles will always be even less efficient than the Carnot cycle for given values of a and b , since no real cycle can be made fully reversible.

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Bibliography: Carnot, Sadi, *Reflections on the Motive Power of Fire*, trans. by James Fox (1986); Huang, F. F., *Engineering Thermodynamics* (1988); Sandfort, J. F., *Heat Engines* (1962; repr. 1979).

See also: ABSOLUTE ZERO; ADIABATIC PROCESS; ENTROPY; ISOTHERMAL PROCESS.

chemical energy

Chemical reactions are accompanied by energy changes that usually are observed as an absorption or emission of heat or light. This energy is associated with the formation and breaking of chemical bonds and is called chemical energy. Germain Henri Hess (1802-50) carefully measured the quantities of heat evolved in chemical reactions and showed that the amount of heat produced or absorbed would be the same for a given set of reactants and products regardless of the intermediates. This generalization is known as HESS's LAW. Because of his many contributions, Hess is considered the "father of thermochemistry."

Energy changes are measured in a CALORIMETER, a reaction chamber usually surrounded by a known quantity of water, the temperature of which is measured before and after the reaction. The HEAT CAPACITIES of the water and the vessel are known, and the amount of energy absorbed (temperature lowered by the reaction) or evolved (temperature raised by the reaction) can be calculated. The reaction is called endothermic if heat is absorbed, exothermic if heat is evolved.

Molecular structure is related to chemical energy through the CHEMICAL BOND. Energy is required to break a chemical bond between two atoms. The reverse process, bond formation, evolves energy. Thus, bond breaking is endothermic and bond making is exothermic. The stronger the bond, the more energy is required to break it; conversely, more energy is evolved when the bond is formed. A chemical reaction's heat effect is correlated with the number and type of chemical bonds broken or formed during the reaction.

Chemical energy is used in many ways, all involving the conversion of chemical energy to a different energy form. Fossil fuels such as coal and oil supply most industrial energy. Coal is essentially carbon and, when oxygen is present, burns to produce carbon dioxide and heat energy. This reaction liberates 94.1 kcal (kilocalories) for every mole of carbon burned. Octane, a component of gasoline, burns in oxygen to liberate 1,300 kcal for every mole of octane. The battery converts chemical energy directly to electricity; and certain chemicals, when mixed together, directly produce light in a manner similar to that of a firefly.

All living organisms use chemical energy. It is the driving force of all life processes. The chemical energy evolved by exothermic reactions in the organism is used to fuel the endothermic reactions vital to life. This energy transfer is a direct use of chemical energy.

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Bibliography: Clay, D. C., ed., *The Theory of Chemical Reaction Dynamics* (1986); Rock, P. A., *Chemical Thermodynamics* (1983).